

FINAL REPORT, September 10, 1997

GRANT No. NAGW-4987

"Coronagraphic Observations of Lunar Sodium"

PI: D.M. Hunten  
The University of Arizona

Co-investigator: Dr. A.L. Sprague

Monitor: Dr. R. Beebe

Start date: 1/1/96, end date 12/12/96 extended to 6/30/97

This grant supported an investigation of lunar sodium by our coronagraph and spectrograph on nearby Mount Lemmon. We report successful operation and data analysis during International Lunar Atmosphere Week, September 15 - 22, 1995, and submittal of a paper to *Icarus*.

The core of the proposed work was to observe the lunar sodium atmosphere with our classical Lyot coronagraph and specially-built grating spectrograph on Mount Lemmon, a 9400-foot peak about an hour's drive from Tucson. It is optimized for low scattered light and for observing from the Moon's limb to an altitude of  $\sim 1$  lunar radius. The grating has 600 lines/mm and a blaze angle of  $49^\circ$ , and is used with a somewhat wide slit at a resolving power of about 5000. It is called DARRK for the initials of the people who designed it. The rejection of stray light from the Moon's disk is spectacularly good: when the sky is clear this light is absent right up to a few arcsec from the limb. We use an excellent 1024 by 1024 pixel CCD camera, operated at  $-100^\circ\text{C}$ ; the exposures are 10 to 30 min. Data reduction is done with IRAF running on a Sun Sparcstation.

During February and March 1995 we employed a physics graduate, Rob Morris (one of the R's in DARRK and previously a JOVE summer fellow) to spend every night trying to observe the Moon. The performance was excellent, but the weather was very bad: only 4 nights were good and 5 or 6 others usable. Even away from the mountains the period

was unusually cloudy, and there was additional local cloudiness at Mount Lemmon, which at 2800 m (9400 ft) is an excellent site in many other ways. In trying to analyze these data, we found that they could not be used because there was not enough auxiliary information (flat fields, day-sky exposures). In addition, the alignment of the image rotator (a Dove prism) turned out to be exceedingly difficult, and the mounting we had provided did not have enough degrees of freedom.

Although the Dove prism is mentioned in most optics textbooks, we have been unable to find any published information on its requirements for alignment. They are simple enough once worked out: the long face must be parallel to the axis of rotation, and this axis must coincide with that of the telescope. Now that the Dove is properly aligned, it behaves very well and needs little or no touching up.

As a consequence, our first truly successful run was that of International Lunar Atmosphere Week, September 15 - 22, 1995. The results have been submitted for publication (Sprague *et al.*, 1997), and this paper is summarized below.

Figure 1 shows a processed frame from Sept. 20, both in the form of an image and as spectral scans obtained at various heights above the limb. Intensities for this and another exposure are plotted in Fig. 2; the geopotential height scale is used to allow for the large variation of gravity with height. The apparent scale heights  $H^*$  are obtained from the slope, and by means of a Chamberlain model (Sprague *et al.*, 1992) are converted to a true scale height  $kT/mg$ . The temperatures  $T$  are 1424 and 1468 K; there is no particular reason why the velocity distribution should be Maxwellian, so this "temperature" is simply a convenient way to represent the distribution by a single number. In fact, one data set from the lunar north pole in Sept. 19 has a strong curvature in a plot like Fig. 2, and may be influenced by a very recent discrete effect such as a meteoroid impact.

Data from this and other exposures during the week are summarized in Table 1. Except for the first night and the Sept. 19 frame just mentioned, the points are well fitted by a straight line, and the temperatures are strongly suprathemal, as previously found by us and other observers. The equatorial results for Sept. 15 are best fitted by two temperatures, one thermal and one suprathemal. We have previously found similar behavior for data taken very near the subsolar point, and have explained it in terms of

*competing release mechanisms* (Sprague *et al.*, 1992). The poorly-understood suprathermal process is present everywhere on the sunlit surface; the thermal one is able to compete only in the warmest areas.

Table 1. Summary of results.

Date	frame #,		Scale	Scale		$4 \pi I$	n	N zenith
Sept.,	slit	LSZ	Height	Height	T (K)	Rayleighs	atoms cm <sup>-3</sup>	10 <sup>8</sup> atoms
1995	location	A	H*	H				cm <sup>-2</sup>
17	#11, eql	~6	279	220	985	554	5.2	1.5
			350	267	1047	478	3.7	1.4
			70	66	295	359	7.3	0.52
	#14, eql		407	307	1376	440	4.0	1.8
			350	267	1047	419	3.1	1.2
			70	66	295	514	9.3	0.66
18	#9, eql	~17	334	257	1149	376	2.9	1.1
			378	287	1284	462	3.6	1.5
	#18, npl	~88	394	298	1334	800	6.2	2.6
			374	284	1271	800	6.3	2.6
19	#7, eql	~28	394	298	1334	711	5.5	2.3
	#8, eql		393	297	1331	631	4.9	2.1
	#14, npl	~88	430	324	1451	138	1.0	0.47
20	#8, eql	~39	422	318	1424	663	4.9	2.2
	#9, eql		435	328	1468	575	4.2	2.0

LSZA, local solar zenith angle; H\*, apparent geopotential scale height, km; n, number density at surface; N, column abundance.



